world as possible before VR is understood and adapted well. The extent to which the user feels present in the environment indicates its success. Therefore, usability issues will diminish the sense of presence in a virtual environment. Users will not be able to experience the reality of a virtual environment if they struggle to use the environment. D. Geszten et al. [38] suggests that presence and copresence should be the primary goals when designing VR environments and should be examined when evaluating the usability of these environments.

## 5. Factors Contributing to Cybersickness

Many potential factors contribute to simulation sickness in virtual environments, such as age, gender, calibration, experience, and application type. P.J Costello [5] has tabulated many of these factors based on the individual, simulator type, and task performed. These factors have a profound impact on the severity of cybersickness. The factors affecting virtual reality are classified according to user, design, display types, and type of VR content. Table 4, provides an overview of some of the factors that contribute to simulation sickness.

### *5.1. Users*

#### 5.1.1. Age

Cybersickness is primarily based on sensory conflict theory and postural in-stability theory. Literature suggests that younger people are more resistant to simulation sickness [32]. Vestibular perceptual threshold, the weakest stimulus detected, diminishes in humans after the age of 40, making them more susceptible to simulation sickness [39]. Era et al. reported that there were postural balance differences between young and middle-aged test participants. In addition, higher age groups experience diminished postural balance which may lead to sickness [40].

#### 5.1.2. Gender

Simulation sickness may vary according to gender with the use of HMDs. Schafer et al. [41] studied the role of gender, technology, and their potential contribution towards simulation sickness. Using the data obtained from about 223 individuals (108 male and 115 female) they examined the levels of simulation sickness with regards to gender, sensory conflict, and improvements in VR technology. They concluded that women experienced a higher level of simulation sickness compared to men. Stanney et al. [42] conducted multiple experiments and found that females were equally susceptible to motion sickness, and it was due to the improper fit of the VR headset to inter-pupillary distance (distance between the center of one's eyes). They also suggest a redesign to the VR headsets with alterable inter-pupillary distance to reduce the cybersickness in women.

#### 5.1.3. Exposure

Stanney et al. [43] concluded that an increase in exposure time was directly proportional to the severity of adverse symptoms. Users vulnerable to motion sickness can experience approximately twice the intensity compared to non-susceptible individuals. Users who experience nausea during carnival rides can also expect unpleasant symptoms. Exposing an individual to virtual environments briefly and stopping the encounter before or while experiencing sickness then retrying in a day or two will help the user adapt to the virtual environment. Recurring exposure to virtual environments may lower or eliminate simulation sickness. However, using a virtual environment for longer durations is not recommended [32].

#### 5.1.4. Control

User control and navigation are substantial contributing factors to simulation sickness since input devices, such as data gloves, keyboards, and mice, can be used to control the virtual environment. Greater environmental control may reduce illness and allow users to expect a reaction after an action is performed [15]. Saredakis et al. [44] observed that physical navigation, such as walking, reduces symptoms compared to navigating through controllers.

### 5.2. Displays

A difference in environments, such as desktop VR, large curved screen displays, or HMD's can have a varied impact on the level of sickness [15].

#### 5.2.1. Head Mounted Display (HMD)

Factors such as contrast, illumination, exposure duration, and working distance contribute to straining the visual system when working with head mounted displays. Approximately 60% of users reported symptoms such as visual strain, nausea, and headache, while 20% reported a reduction in binocular visual perception when using a stereoscopic HMD, such as EyePhone LX, in an immersive virtual environment for a ten-minute duration [45]. Similar symptoms were experienced by 61% of users after twenty minutes of exposure to immersive virtual content from a DVisor HMD [46]. Technical advancements in VR display hardware, comparing Oculus VR DK1 to Oculus VR DK2, for example, did not have a significant impact on decreased cybersickness [41]. Some symptoms are more likely to occur in virtual environments. However. sensory conflict contributes significantly to nausea and other symptoms. Body motion, head movement-initiated disorientation, and incorrect optical design resulted in strain-producing ocular symptoms. Recent contributions from Tong et al. [47] determined that HMD use caused a higher level of motion sickness compared to stereoscopic desktop displays. Some users enjoyed a higher level of immersion in an HMD. However, they could not sustain the experience for longer periods.

#### 5.2.2. Large and Desktop Displays

Former investigations report that viewing time, viewing distance, and lighting may also contribute to simulation sickness [48,49]. The optimum viewing distance is 65 cm. Swindells et al. concluded that large displays improve a sense of presence, but they do not directly impact or induce simulation sickness [50].

**Table 4.** Factors contributing to simulation sickness.

| Factors | Type | Effects | References |
|---|---|---|---|
| User | Age | Younger and middle-aged people are more resistant to sickness than older adults | [39,40] |
| | Gender | Females are more prone to motion sickness than Males | [41,42] |
| | Exposure to VR | Longer VR exposure durations are directly proportional to the severity of sickness. | [43] |
| | Control | Users navigating with virtual controls might experience higher levels of cybersickness than those who use physical navigation | [15,44] |
| Display | Head-Mounted Displays | Produce high levels of cyber sickness. | [45,46] |
| | Large displays | Do not directly impact or induce sick-ness | [48–50] |
| | Immersion VR Content | Non-immersive content triggers less simulation sickness. The reverse is also true | [51] |
| | Graphic Realism | Realistic graphic content can cause more simulation sickness. | [2] |
| | Field of view | Altering the FOV minimizes user discomfort. | [2,8] |

### 5.3. VR Content Type

#### 5.3.1. Immersion

Guna et al. studied the impact of virtual content type on simulation sickness. They noticed that the type of video content, immersive vs. non-immersive, is a critical factor for virtual environment usability. Video content type influenced the contributor's sensitivity to simulation sickness and physiology. Their conclusion was based on the results of a simulation sickness questionnaire and other physiological measures. The lowest simulation sickness questionnaire score was recorded for non-immersive virtual content displayed on a television screen, while the highest scores were reported on an HMD with immersive content [51].

#### 5.3.2. Graphic Realism

Chang et al. investigated the results of rendering realistic scenes. Participants who experienced realistic graphic content were prone to a higher level of simulation sickness. The authors also suspect that a sensory discrepancy between the vestibular and visual systems may cause a higher level of discomfort [2].

#### 5.3.3. Field of View

Field of view (FOV) is the maximum visual angle of the virtual environment display. It is the visual range of the virtual world through the HMD or other display device. Altering the FOV of a display manually or dynamically significantly reduces user discomfort during swift and rotating movements [2,8].

### 5.4. Design

The virtual reality (VR) environment is a rapidly emerging technique for simulating real-world applications. Examples of successful application domains include training, therapy, and design. Simulating realistic features that support a wide range of activities is difficult, even with recent developments. Designing and executing virtual environments with a high degree of similarity to the real world is a significant challenge since human interactions are highly associated with sensory information. Minimal training is needed for interacting when the simulated system is close to natural, which correlates well to the system's usability. Sustaining realism in the simulated world has its benefits. However, if the virtual environment is far from real, there is a need for remarkable visual patterns based on the application environment. Virtual reality, by definition, comprises immersive environments that use multi-modal inputs, such as haptic, visual, and speech, and outputs, such as HMD's and other displays, to create a maximum presence for the user. Designing complex virtual environments is a delicate task since it requires managing hardware, general user safety, and visual content that may cause disorientation or sickness. The design process for desktop VR environments is straightforward. However, the presence it draws is minimal and is less effective in tasks that include physical interaction [52].

## 6. Guidelines to Minimize Simulation Sickness

Hardware improvements improve the usability of virtual environments [53], and existing research suggests that some techniques used to achieve maximum usability can minimize simulation sickness [54]. Virtual reality hardware manufacturers, such as Oculus and HTC, have detailed design guidelines for content developers and hardware safety guidelines for users [55].

### 6.1. Design

It is impossible to have an ideal set of guidelines for any software system. However, we have summarized some critical ones from existing research, that must be considered when designing virtual environments to reduce simulation sickness symptoms.